DEFORMATION ANALYSIS OF REINFORCED EARTH WALL SUBJECTED TO APPLIED LOADS

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To my beloved wife and parents

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ABSTRACT

Reinforced Earth (RE) wall has been used widely in Malaysia. However, not much study has been implemented on the deformation of RE Wall subjected to various applied loads. This study focuses on the behavior of original Reinforced Earth wall where high friction reinforcing strips are used as soil reinforcement. Finite element models are used to simulate the response of the RE Wall under the various type of applied loads. Field instrumentations are used to measure the actual deformation of RE wall on site. The field lateral movements of RE wall at facing panels under the applied loads are compared with the analysis result. From the results, the suitability of the soil models for RE wall modeling can be pre-determined. Parametric study are performed on the response finite element models with various RE strip length over wall height ratios (L/H) subjected to traffic loads, bridge loads and horizontal loads due to compaction force. Based on series of parametric studies, correlation between *L/H* ratios subjected to various loads can be obtained and location of maximum lateral deformation at the wall facing can be pre-determined. Besides that, finite element analysis was performed on the RE wall with trapezoidal approach subjected to traffic live load. Saving on strip length based on trapezoidal approach without jeopardizing the wall deformation are discussed.

ABSTRAK

Tembok tanah bertetulang atau ñReinforced Earth wallò telah diguna secara luasnya di Malaysia. Namun, tidak banyak kajian dijalankan untuk mengenal pasti perubahan bentuk tembok di bawah pelbagai beban. Kajian ini menumpu kepada sifat tembok tanah bertetulang asal dengan tetulang leper yang mempunyai geseran tinggi terhadap tanah berkelikir. Kaedah unsur terhingga digunakan untuk mengkaji kesan tindakan tembok tanah bertetulang akibat pelbagai beban. Di samping itu, pengukuran dijalankan di tapak untuk mengetahui keadaan perubahan bentuk tembok yang sebenar. Data-data pergerakan mendatar muka tembok yang diperolehi di tapak digunakan untuk membuat perbandingan dengan keputusan-keputusan analisa kaedah unsur terhingga. Justeru, pemodelan juzuk tanah yang sesuai untuk model tembok tanah bertetulang akan dipilih. Selepas itu, kajian parameter dijalankan secara berulangan untuk mengenal pasti sambutan modal-modal unsur terhingga dengan pelbagai nisbah panjang tetulang terhadap ketinggian tembok (*L/H*) terhadap beban lalulintas, beban daripada jambatan, dan beban mendatar yang disebabkan oleh kesan pemadatan. Berdasarkan siri kajian berulangan, perkaitan antara nisbah *L/H* di bawah pelbagai jenis beban akan diperolehi. Di samping itu, kajian unsur terhingga juga dijalankan terhadap tembok yang mempunyai pendekatan trapezoid pada panjang tetulang. Penjimatan yang dihasilkan daripada penggunaan dinding trapezoid pula dibincangkan dalam kajian ini.

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LIST OF SYMBOLS

B, L	-	Reinforced Earth strip length
b	-	Width of strip
c'	-	Effective cohesion
D	-	Length of strip at active zone
E_{ref}	-	Youngôs modulus
E_{50}^{ref}	-	Secant stiffness in triaxial test
E_{oed}^{ref}	-	Tangent stiffness in oedometer test
E_{ur}^{ref}	-	Unloading/ reloading stiffness
f^*, μ^*	-	Friction factor of reinforcing strip
H	-	Reinforced Earth wall height
H'	-	Elevated wall height
H_m	-	Reinforced Earth mechanical height
K	-	Coefficient of earth pressure within the RE block
K_a	-	Coefficient of earth pressure
K_o	-	Coefficient of earth pressure at rest
K_r	-	Coefficient of earth pressure due to compaction
K_o^{NC}	-	K_o value for normal consolidation
k_x	-	Permeability in horizontal direction
k_y	-	Permeability in vertical direction
M	-	Moment of loads
m	-	Power of stress level dependency stiffness
N	-	Number of strips
P	-	Resultant force
p'	-	Mean effective stress
p^{ref}	-	Reference stress for stiffness
R_f	-	Failure ratio

R_{inter}	-	Interface reduction factor
T_f	-	Frictional resistance
T_{max}	-	Maximum tensile stress in the reinforcing strip
T_o	-	Maximum tensile stress across connection
ΣV	-	Total vertical loads
W	-	Reinforced Earth block self weight
z_1, z_2, z_3	-	Reinforced Earth block height
δ	-	Inclined angle of resultant force at back of wall
δ_h	-	Horizontal deformation
δ_{max}	-	Maximum horizontal deformation
δ_R	-	Relative displacement
σ_1', σ_2', σ_3'	-	Major, intermediate and minor principal stress respectively
σ_v, σ_n	-	Vertical stress
σ_h	-	Horizontal stress
ϕ	-	Internal friction angle for soil
ϕ'	-	Effective internal friction angle of soil
$\gamma_1 Z$	-	Weight of the fill above reinforcing strip
γ_{unsat}	-	Unsaturated soil weight
γ_{sat}	-	Saturated soil weight
λ_f	-	Partial safety factor
τ	-	Maximum shear stress
ν	-	Poissonôs ratio
ν_{ur}	-	Poissonôs ratio for unloading/reloading
ψ	-	Dilatancy angle

CHAPTER 1

INTRODUCTION

Reinforced earth (RE) is a composite construction material in which the strength of engineering fill is enhanced by the addition of strong inextensible tensile reinforcement in the form of strip (Ingold, 1982). The basic mechanism of reinforced earth involves the generation of frictional forces between the soil and the reinforcement. These forces enhance the strength of the composite. Basically, these structures consist of two basic components, namely engineering fill and reinforcement, as well as some form of facing to prevent surface erosion and give an aesthetically pleasing finish (Figure 1.1).

Massive gravity-type retaining walls were the first and remain the widest spread application of Reinforced Earth. The term ñmassiveò clearly implies that the material, even though composite and flexible, forms a continuous, homogeneous block. In addition to its own weight, the block transfers the effects of surcharges and earth pressures to the foundation, and distributes them evenly over the entire width of its base. Due to the flexibility of the wall, this wide foundation prevents concentration of loads, making it possible to build a wall directly on the ground, even on very poor foundation soils.

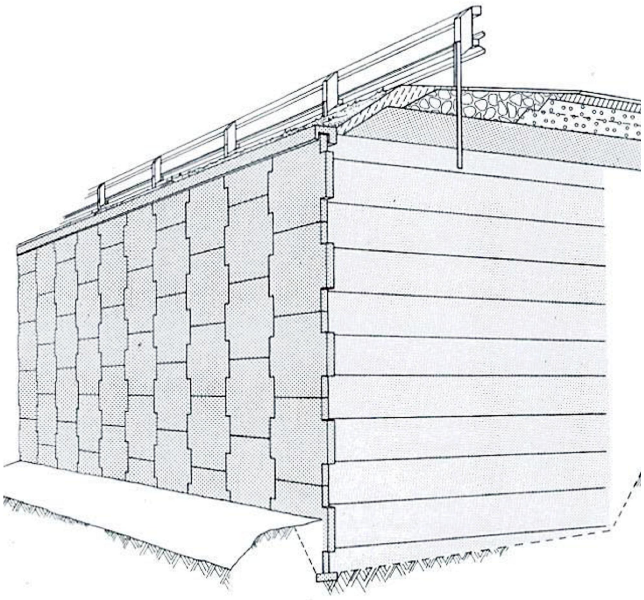

Figure 1.1: The component of Reinforced Earth wall (REMS, 2008a)

Since the invention of RE system by Henri Vidal, the French architect in 1967, numerous RE walls have been designed and constructed all over the world. The capability of supporting high applied load allows the RE wall to be used in wide variety of applications, including embankment walls in highway, slope embankment, bridge abutment, railway crossing, river walls, and many industrial and military applications (REMS, 2008a). In Malaysia, more than 100,000 numbers of walls were constructed since 1978 (REMS, 2008a). The highest RE wall ever constructed in Malaysia was in Jalan Semantan, Kuala Lumpur with the maximum height of 25m in three tiers (REMS, 2008b).

As stated by British Standard Institution (BSI) (1995), the design of RE wall shall involve internal and external stability checks. The general guidance by BSI is the reinforcing strip length shall be more than 70% of the height of wall. The external stability checks of the wall are performed on sliding, overturning and bearing failure. As for internal stability design, checking is done on the tensile strength of steel strips and frictional resistance against horizontal force. In this case, elastic perfectly plastic behavior was assumed for the steel strips.

1.1 Background of Problem

Practicing geotechnical engineers often work under tight schedule and financial constraint (Law, 2008). Therefore, simple analyses on internal and external wall stability are performed to verify their design. However, there are some shortcomings associated with the analyses. Firstly, deformations of the wall are generally not considered in design. The designers normally assume that as long as the design has fulfilled the stability checks, deformation of wall will be in order. Secondly, the behavior of RE wall under different applied loads, whether is under construction stage of post construction stage are unable to be predicted. Thirdly, the design is time independent.

Performance of RE wall is related to both stability and deformation. The performance is always verified by extensive instrumentation program such as inclinometer, which measures the deflection profile of wall facing, ground settlement markers, load cells, strain gauges and etc. It is important to study and review the measured field performance of wall deformation because it provides insight through experiences gained during design and construction of real construction.

Moreover, there are the needs to determine the relationship between the deformations of RE wall and the applied loads, such as dead load and live load, under various strip length over wall height ratios (*L/H*) to ensure that the as-built RE wall is still within the tolerance, road alignment or right of way after any possible movements. The alignment at the top of wall shall be within the tolerance of the setting out alignment pegged during the initial installation of the wall panel at the base. For the vertical movement, or settlement of the wall, it is dependent on the foundation soil supporting the wall. Weak foundation supporting the wall will result in greater settlement of wall as compared with stiff foundation.

To predict the deformations, computer aided softwares are required. With the assistance of finite element software such as PLAXIS, FLAC and COSMO, greater understanding of the behavior of RE structures can be achieved. These analysis allows deformations of RE wall vertically and laterally to be predicted. Hence, numerical analysis acts as an additional check for the conventional RE wall design.

1.2 Problem Statement

Deformations are generally not explicitly considered in the design of RE wall. Experience indicates that the deformations of well-designed RE walls constructed using granular backfill are generally acceptable. Even though British Standard (BSI, 1995) stated that under the serviceability limit state, the potential mechanism of post construction internal movement should be considered, no guide was given to justify the deformations.

Instrumentation data from RE wall project can be used to back-analyzed the predicted wall horizontal displacement and ground settlement. These data are very useful for analyzing and studying the effect of applied load on the deformation behaviors of the wall.

Finite element method provides a means of analyzing both stress distribution and deformations in RE wall. The method can be used to analyze the response of the wall when subjected to applied load and the results can be compared with the response of an actual RE wall.

This project focuses on the application of the Mohr-Coulomb model and the Hardening Soil model implemented in PLAXIS version 8.2 on analyzing the deformation behavior of RE wall subjected to various applied loads. The selected site is in Sungai Buloh, Selangor Darul Ehsan with single tier RE wall constructed. A comparison between the Mohr-Coulomb and Hardening Soil model with field instrumentation results are carried out to confirm the suitability of model types for RE wall in the modeling. In other words, it is to confirm whether a simple linear finite element analysis or a complex non-linear numerical analysis is sufficient for the sound engineering practice.

With the confirmed results above, the correlation between the wall deformation, *L/H* ratios and applied loads is established. Recommendation is also given on the possibility to apply shorter strips length at lower half portion of wall to reduce granular backfill quantities and excavation without jeopardizing the allowable deformation.

1.3 Objectives of the Study

The objectives of this study are as follow:

i. To select the most suitable soil models for modeling RE wall in PLAXIS finite element program.
ii. To study the effect of various applied loads on RE wall lateral deformation.
iii. To evaluate the effect of *L/H* ratio in the deformation of wall.
iv. To prove that trapezoidal wall provide economical design

1.4 Scope and Limitation of the Study

Only one project of RE wall is included in the study. The scope of study and discussion are limited to the measured lateral deformation of the wall. Other factors such as settlement of the wall, influence of granular backfill size distribution are not included in this study.

The back-analysis is carried out using commercial 2D finite element program, which is PLAXIS version 8.2. The soil constitutive models used in this case study are limited to Mohr-Coulomb and Hardening Soil models implemented in this 2D computer program. It is therefore believed that computer analysis using 3D approach shall provide the more accurate analysis.

The effect of the use of different type of compactor is not considered in this study. For the compaction of granular backfill at back of wall panel, the 1.5m zone next to the wall facing panel shall be compacted using hand compactor or baby roller; the remaining of the backfill zone shall be compacted using 1 tone vibrating roller.

In this study, it is assumed that the filling of the embankment fill behind the reinforced earth block shall be performed concurrently with the filling of granular backfill within the block. The effect of delay in embankment filling that cause the differential in level is not considered in the study.

The backfill material used for RE wall is assumed to be purely granular or sand. The study excludes the possibility of backfill material accidentally mixed with earth during the construction, which may reduce the internal friction angle assumed in the study.

Also in this study, the temperature of the reinforcing strip is not taken into account in finite element analysis. The strips are assumed to be perfectly jointed to the wall concrete facing panel.

1.5 Significance of the Study

This study presents the performance of RE wall with the numerical analysis results, aimed at confirming the suitable soil constitutive model for the wall modeling. With the confirmed suitable soil model, correlation between the wall deformations, applied loads and *L/H* ratios are aimed to be established based on finite element analysis.

The correlation suggested in this study provide the geotechnical engineers a simple way to estimate wall deformation with the given wall height and applied loads. This is important to ensure that the designed wall is still within the deformation limitation.

Throughout this study, steps on numerical modeling of reinforced earth wall are discussed. Guidance is also given on application of finite element method in designing RE wall using PLAXIS version 8.2.

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